

CONTINUATION IN PART

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## **OLED DISPLAYS WITH FIBER-OPTIC FACEPLATES**

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## **OLED DISPLAYS WITH FIBER-OPTIC FACEPLATES**

This is a continuation-in-part of application U.S. Serial No. 10/201,338 filed July 23, 2002.

### **FIELD OF THE INVENTION**

5           The present invention relates to the use of fiber-optic faceplates with organic light emitting diode (OLED) flat-panel electro-optic devices and optical systems.

### **BACKGROUND OF THE INVENTION**

10           Organic light emitting diodes (OLED) have many advantages in a flat-panel display device and are useful in optical systems. US Patent No. 6,384,529 issued May 7, 2002 to Tang et al. shows an OLED color display that includes an array of OLED light emitting elements (pixels). Light is emitted from a pixel when a current is passed through an organic material, the frequency of the light depending on the nature of the organic material that is used. The organic  
15           materials are placed upon a substrate between electrodes, with an encapsulating cover layer or plate. In such a display, light can be emitted through the substrate (a bottom emitter) or through the encapsulating cover (a top emitter), or both. The emitted light is Lambertian, that is it is emitted equally in every direction. While this is a useful feature in a flat-panel display because the resulting viewing angle  
20           is very wide, it is also problematic in that a significant fraction of the light emitted from the OLED materials is internally reflected within the cover or substrate a number of times before being emitted from the display. When such OLED displays are used in optical systems having large numerical apertures such as the head mounted display shown in US 6,181,304, issued Jan 30, 2001 to Robinson et  
25           al., or are viewed at large viewing angles, the internal reflections in the substrate or cover plate reduce the sharpness of the display.

          There is a need therefore for an improved OLED flat-panel display device with improved sharpness.

### **SUMMARY OF THE INVENTION**

30           The need is met according to the present invention by providing an OLED display device that includes a substrate; an array of OLED elements formed on the substrate, the OLED elements defining an optical cavity for

reducing the angle of emission of light from the OLED elements; an encapsulating cover disposed over the OLED elements; and the display device being viewed through the substrate and/or the cover and wherein the substrate and/or the cover through which the display is viewed is a fiber-optic faceplate, whereby the  
5    apparent sharpness of the display device is improved.

### **ADVANTAGES**

The present invention has the advantage that it increases the sharpness of an OLED display device when used in an optical system having a large numerical aperture or viewed from a wide viewing angle.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

Fig. 1 is a cross-sectional partial view of a prior art bottom-emitter OLED display device.

Fig. 2 is a schematic diagram illustrating a prior art heads up display system having a large numerical aperture optical system.

15    Fig. 3 is a partial cross sectional view of a bottom-emitter OLED display device having a fiber optic face plate according to the present invention.

Fig. 4 is a partial cross sectional view of a top-emitter OLED display device having a fiber optic face plate according to the present invention.

Fig. 5 is a partial cross sectional view of an OLED display device  
20    according to the present invention, having one fiber per light emitting element.

Fig. 6 is a partial cross sectional view of an OLED display device according to the present invention, having one fiber for each three-color emitting subpixels.

Fig. 7 is a schematic diagram illustrating an OLED display device  
25    having a fiber optic face plate with a curved surface.

Fig. 8 is a graph showing an edge transition in a prior art OLED display device.

Fig. 9 is a graph showing an edge transition in an OLED display device according to the present invention.

30    Fig. 10 is a partial cross sectional view of a tiled display having tapered fiber optic face plates.

Fig. 11 is a more detailed schematic diagram of a prior art OLED device.

### **DETAILED DESCRIPTION OF THE INVENTION**

The present invention is useful for both top-emitting OLED devices (those that emit light through a cover placed above a substrate on which the OLED is constructed) and bottom-emitting OLED devices (those that emit light through the substrate on which the OLED is constructed).

Referring to Fig. 1, a prior art bottom-emitting OLED device 10 includes a transparent substrate 12, a first electrode 18, regions of OLED material forming light emitting pixels 19, a second electrode 30, and electrode protection layer 32, and an encapsulating cover 36 forming a gap 34 above the protection layer 32. Light is emitted from a pixels 19 and experiences internal reflections in the substrate 12. As shown in Fig. 2, when employed in a large numerical aperture optical system 60, such as a head mounted display that is viewed by a human eye 62, through a large numerical aperture lens 61, multiple images of the pixel are formed as shown by rays A and B, thereby reducing the apparent sharpness of the display. As used herein, the term large numerical aperture means a system having a numerical aperture greater than 0.25. This sharpness reducing phenomenon is also experienced when such a display is viewed normally at a large angle from the optical axis.

A top emitting device is similar to the bottom emitting device shown in Fig. 1 except that the cover 36, the second electrode 30, and the electrode protection layer 32 are transparent. The same problem of sharpness reducing multiple images exists.

In the Figures it is understood that, for simplicity and clarity, not all of the components or layers are shown and that the layers are not drawn to scale. In practice, the OLED layers 19, 30, 32 are very thin compared to cover 36 and substrate 12.

Referring to Fig. 3, in a bottom emitting display according to the present invention, substrate 12 is a fiber-optic faceplate. A fiber-optic faceplate 12 (or array of light pipes) is composed of many parallel fibers 40, preferably oriented orthogonal to the surface of the faceplate that transmit light through the

fibers but not between fibers or from one fiber to another. Suitable fiber optic faceplates are commercially available, for example from Schott Corporation, Yonkers, New York. Preferably the diameter of the fibers in the face plate is approximately equal to or smaller than the diameter of the light emitting elements

5 in the display such that at least one fiber transmits light from each pixel in the display. Magnifying fiber optic face plates having tapered fibers can be used to enlarge or reduce the apparent size of the image.

The OLED elements are formed on the surface of the fiber optic face plate in the conventional manner. As shown in Fig. 3, light rays A and C that

10 strike the fiber-optic faceplate cannot propagate horizontally through the substrate (as light does through a conventional glass substrate) and will emerge at or very near to the location at which the light entered the fiber optic face plate, thus eliminating the multiple images and enhancing the sharpness of the display.

Because OLED light emitting elements emit light equally in every

15 direction, not all of which will enter the fiber optic face plate, the performance of the present invention can be enhanced by increasing the amount of light that is emitted orthogonally to the surface of the fiber optic faceplate so that a greater percentage of the light will enter the fibers. If the angle at which light is emitted from the OLED light emitting elements into a fiber is very large compared to the

20 axis of the fiber, many reflections will occur within the fiber before the light leaves the other end of the fiber. At each reflection within the fiber, some light is lost due to incomplete reflection. Light emitted into a fiber from an OLED light emitting elements that is parallel to the axis of the fiber will encounter fewer reflections and consequent losses. Hence, reducing the angle at which light enters

25 a fiber will enhance the amount of light propagated through the fiber.

Increasing the amount of light emitted orthogonally to the surface of the OLED light emitting element will also increase the amount of light taken into the fiber. In conventional practice, up to 80% of the light emitted is lost because it is not transmitted through the cover or substrate of the display. Instead,

30 the light may be emitted in a direction parallel to the face of the fiber optic faceplate and will propagate through the light emissive layers by waveguide action. Therefore, reducing the amount of light emitted parallel to the face of the

faceplate that travels by waveguide through the light emissive layers of organic materials will increase the amount of light that is emitted usefully into the fibers of the fiber optic faceplate.

5 A reduced angle of emission from the OLED light emitting elements can be achieved by forming an optical cavity between the electrodes providing current to the OLED light emitting elements. Electrodes can be made of highly reflective, thin layers of metal. By making the electrode opposite to the direction of emission completely reflective and the electrode through which light passes partially reflective, an optical cavity can be formed. The optical cavity is  
10 tuned to the preferred frequency at which light is to be emitted by carefully depositing layers of the required thickness. The light within the cavity will form a standing wave pattern at the desired frequency and with a reduced angle of emission. Optical cavities of this type are known in the art, as are suitable metallic electrodes, for example silver. For example, see  
15 US Patent application 20030184892 published 20031002, by Lu et al., which is incorporated herein by reference. It is also possible to use optical cavity designs that produce coherent laser light as described in published US patent application No. US20030161368 published 20030828 by Kahen et al. and US20020171088 published 20021121 by Kahen et al. which are incorporated herein by reference.  
20 Applicants have demonstrated both incoherent and coherent OLED light emission having a reduced angle of emission that is suitable for the present invention.

In a bottom-emitting display, the electrode 18 must be partially reflective while the electrode 30 can be totally reflective. In a top-emitter configuration, the electrode 18 is reflective while the electrode 30 is partially reflective.

25 Applicants have demonstrated the use of an optical cavity for the enhancement of light emission from an OLED structure with both white-light emitting materials and for red, green, and blue light-emitting materials. In all cases, the use of a properly sized cavity with the use of a thin layer of silver or silver compounds as the partially reflective electrode and a thicker layer of either  
30 silver or aluminum or compounds of aluminum or silver as the reflective electrode results in greater light emission orthogonal to the electrodes and with a narrower spectrum. Partially reflective electrodes may also consist of a two-layer structure

in which a first layer is a transparent conductor and a second layer is a partially reflective mirror.

In conventional practice, the use of an optical cavity in a display application has the significant drawback of a color change as the display is viewed at angles other than the orthogonal. In the present invention, no such disadvantage is seen since all of the emitted light that passes into the fiber will be reflected several times and mixed as it passes through the fiber. When the light emerges from the fiber it will be mixed and have no such dependency on viewing angle.

In an alternative embodiment of the present invention, a fiber-optic faceplate is used as the cover 36 of a top-emitting OLED display device. Referring to Fig. 4, the layers of the OLED device are formed conventionally on a substrate 12, and the device is encapsulated using the fiber-optic face plate as an encapsulating cover. In operation, the light emitted by the OLED pixels 19 traverses the gap 34 and is coupled into the fiber-optic cover from which it is emitted as described above for a bottom-emitting OLED device. Preferably, the gap 34 is filled with a transparent material having an index of refraction matching the fiber optic face.

Referring to Fig. 5, the fiber-optic faceplate used as a cover 36 for a top emitter OLED display has one fiber or light pipe 40 for each light emitting pixel element 19. Referring to Fig. 6, the display is a color OLED display wherein each light emitting pixel includes color subpixels 19R, 19G and 19B, for emitting red, green and blue light respectively. One fiber or light pipe 40 is employed for the entire three-color pixel. Alternatively, one fiber for each subpixel may be employed.

Referring to Fig. 7, according to one embodiment of the present invention, the fiber-optic faceplate 36 has one flat face 41 arranged adjacent to the OLED light emitters 19 and a second face 42 that is not parallel to face 41, (for example having a spherical surface as shown in the Fig. 7). This arrangement can be used in either a top or bottom emitting OLED display device. For example, a spherical wave front can be efficiently created by utilizing a fiber plate with one flat side and the other side having a spherical surface as shown in Fig. 7. The

spherical surface can be, either concave or convex depending on the application in the optical system.

Applicants have compared the present invention with the prior art by fabricating identical bottom-emitter OLED display devices on a glass substrate and on a fiber-optic faceplate. A scan of a transition between a row of light and dark pixels on the device formed on a conventional glass substrate using a microscope having a large numerical aperture resulted in a transition having the form shown in Fig. 8. A microscopic scan of a transition between a row of light and dark pixels on the device formed on the fiber optic face plate resulted in a transition having the form shown in Fig. 9. As can be seen by comparing the graphs of Figs. 8 and 9, the transition measured from the display having the fiber optic face plate is considerably sharper. Tests were performed with the microscope objective oriented both orthogonally to the surface of the device and at an angle to the surface of the devices and similar results were obtained.

Referring to Fig. 10, display devices having tapered fiber optic face plates **38** can be assembled into a tiled display mounted on a support **11**. The tapered face plate has a smaller light receiving surface adjacent the light emitting elements and a larger light emitting surface. The tapered fiber optic face plates **38** serve a dual function of improving the sharpness of the display, as discussed above, while facilitating the tiling of the display. The arrays of light emitting elements **19** can be spaced apart from each other on the support **11**, while the edges of the fiber optic face plates are abutted to provide a seamless appearance to the tiled display.

The invention is preferably employed in a device that includes Organic Light Emitting Diodes (OLEDs) which are composed of small molecule or polymeric OLEDs as disclosed in but not limited to U. S. Patent No. 4,769,292, issued September 6, 1988 to Tang et al., entitled "Electroluminescent Device with Modified Thin Film Luminescent Zone" and U. S. Patent No. 5,061,569, issued October 29, 1991 to VanSlyke et al., entitled "Electroluminescent Device with Organic Electroluminescent Medium. Many combinations and variations of organic light emitting devices can be used to fabricate such a device.



### General device architecture

The present invention can be employed in most OLED device configurations. These include very simple structures comprising a single anode and cathode to more complex devices, such as passive matrix displays comprised of orthogonal arrays of anodes and cathodes to form pixels, and active-matrix displays where each pixel is controlled independently, for example, with thin film transistors (TFTs).

There are numerous configurations of the organic layers wherein the present invention can be successfully practiced. A typical structure is shown in Fig. 11 and is comprised of a substrate **101**, an anode **103**, a hole-injecting layer **105**, a hole-transporting layer **107**, a light-emitting layer **109**, an electron-transporting layer **111**, and a cathode **113**. These layers are described in detail below. Note that the substrate may alternatively be located adjacent to the cathode, or the substrate may actually constitute the anode or cathode. The organic layers between the anode and cathode are conveniently referred to as the organic EL element. The total combined thickness of the organic layers is preferably less than 500 nm.

The anode and cathode of the OLED are connected to a voltage/current source **250** through electrical conductors **260**. The OLED is operated by applying a potential between the anode and cathode such that the anode is at a more positive potential than the cathode. Holes are injected into the organic EL element from the anode and electrons are injected into the organic EL element at the cathode. Enhanced device stability can sometimes be achieved when the OLED is operated in an AC mode where, for some time period in the cycle, the potential bias is reversed and no current flows. An example of an AC driven OLED is described in US 5,552,678.

### Substrate

The OLED device of this invention is typically provided over a supporting substrate where either the cathode or anode can be in contact with the substrate. The electrode in contact with the substrate is conveniently referred to as the bottom electrode. Conventionally, the bottom electrode is the anode, but this invention is not limited to that configuration. The substrate can either be light

transmissive or opaque, depending on the intended direction of light emission. The light transmissive property is desirable for viewing the EL emission through the substrate. Transparent glass or plastic is commonly employed in such cases. For applications where the EL emission is viewed through the top electrode, the transmissive characteristic of the bottom support is immaterial, and therefore can be light transmissive, light absorbing or light reflective. Substrates for use in this case include, but are not limited to, glass, plastic, semiconductor materials, silicon, ceramics, and circuit board materials. Of course it is necessary to provide in these device configurations a light-transparent top electrode.

10 Anode

When EL emission is viewed through anode 103, the anode should be transparent or substantially transparent to the emission of interest. Common transparent anode materials used in this invention are indium-tin oxide (ITO), indium-zinc oxide (IZO) and tin oxide, but other metal oxides can work including, but not limited to, aluminum- or indium-doped zinc oxide, magnesium-indium oxide, and nickel-tungsten oxide. In addition to these oxides, metal nitrides, such as gallium nitride, and metal selenides, such as zinc selenide, and metal sulfides, such as zinc sulfide, can be used as the anode. For applications where EL emission is viewed only through the cathode electrode, the transmissive characteristics of anode are immaterial and any conductive material can be used, transparent, opaque or reflective. Example conductors for this application include, but are not limited to, gold, iridium, molybdenum, palladium, and platinum. Typical anode materials, transmissive or otherwise, have a work function of 4.1 eV or greater. Desired anode materials are commonly deposited by any suitable means such as evaporation, sputtering, chemical vapor deposition, or electrochemical means. Anodes can be patterned using well-known photolithographic processes. Optionally, anodes may be polished prior to application of other layers to reduce surface roughness so as to minimize shorts or enhance reflectivity.

30 Hole-Injecting Layer (HIL)

While not always necessary, it is often useful to provide a hole-injecting layer 105 between anode 103 and hole-transporting layer 107. The hole-

injecting material can serve to improve the film formation property of subsequent organic layers and to facilitate injection of holes into the hole-transporting layer. Suitable materials for use in the hole-injecting layer include, but are not limited to, porphyrinic compounds as described in US 4,720,432, plasma-deposited  
5 fluorocarbon polymers as described in US 6,208,075, and some aromatic amines, for example, m-MTDATA (4,4',4''-tris[(3-methylphenyl)phenylamino]triphenylamine). Alternative hole-injecting materials reportedly useful in organic EL devices are described in EP 0 891 121 A1 and EP 1 029 909 A1.

10 Hole-Transporting Layer (HTL)

The hole-transporting layer **107** contains at least one hole-transporting compound such as an aromatic tertiary amine, where the latter is understood to be a compound containing at least one trivalent nitrogen atom that is bonded only to carbon atoms, at least one of which is a member of an aromatic  
15 ring. In one form the aromatic tertiary amine can be an arylamine, such as a monoarylamine, diarylamine, triarylamine, or a polymeric arylamine. Exemplary monomeric triarylaminines are illustrated by Klupfel et al. U.S. Patent No. 3,180,730. Other suitable triarylaminines substituted with one or more vinyl radicals and/or comprising at least one active hydrogen containing group are  
20 disclosed by Brantley et al U.S. Patent Nos. 3,567,450 and 3,658,520.

A more preferred class of aromatic tertiary amines are those which include at least two aromatic tertiary amine moieties as described in U.S. Patent Nos. 4,720,432 and 5,061,569. The hole-transporting layer can be formed of a single or a mixture of aromatic tertiary amine compounds. Illustrative of useful  
25 aromatic tertiary amines are the following:

1,1-Bis(4-di-*p*-tolylaminophenyl)cyclohexane

1,1-Bis(4-di-*p*-tolylaminophenyl)-4-phenylcyclohexane

4,4'-Bis(diphenylamino)quadriphenyl

Bis(4-dimethylamino-2-methylphenyl)-phenylmethane

30 N,N,N-Tri(*p*-tolyl)amine

4-(di-*p*-tolylamino)-4'-[4(di-*p*-tolylamino)-styryl]stilbene

N,N,N',N'-Tetra-*p*-tolyl-4-4'-diaminobiphenyl

- N,N,N',N'-Tetraphenyl-4,4'-diaminobiphenyl  
 N,N,N',N'-tetra-1-naphthyl-4,4'-diaminobiphenyl  
 N,N,N',N'-tetra-2-naphthyl-4,4'-diaminobiphenyl  
 N-Phenylcarbazole
- 5 4,4'-Bis[N-(1-naphthyl)-N-phenylamino]biphenyl  
 4,4'-Bis[N-(1-naphthyl)-N-(2-naphthyl)amino]biphenyl  
 4,4''-Bis[N-(1-naphthyl)-N-phenylamino]p-terphenyl  
 4,4'-Bis[N-(2-naphthyl)-N-phenylamino]biphenyl  
 4,4'-Bis[N-(3-acenaphthenyl)-N-phenylamino]biphenyl
- 10 1,5-Bis[N-(1-naphthyl)-N-phenylamino]naphthalene  
 4,4'-Bis[N-(9-anthryl)-N-phenylamino]biphenyl  
 4,4''-Bis[N-(1-anthryl)-N-phenylamino]-p-terphenyl  
 4,4'-Bis[N-(2-phenanthryl)-N-phenylamino]biphenyl  
 4,4'-Bis[N-(8-fluoranthryl)-N-phenylamino]biphenyl
- 15 4,4'-Bis[N-(2-pyrenyl)-N-phenylamino]biphenyl  
 4,4'-Bis[N-(2-naphthacenyl)-N-phenylamino]biphenyl  
 4,4'-Bis[N-(2-perylenyl)-N-phenylamino]biphenyl  
 4,4'-Bis[N-(1-coronenyl)-N-phenylamino]biphenyl  
 2,6-Bis(di-p-tolylamino)naphthalene
- 20 2,6-Bis[di-(1-naphthyl)amino]naphthalene  
 2,6-Bis[N-(1-naphthyl)-N-(2-naphthyl)amino]naphthalene  
 N,N,N',N'-Tetra(2-naphthyl)-4,4''-diamino-p-terphenyl  
 4,4'-Bis{N-phenyl-N-[4-(1-naphthyl)-phenyl]amino}biphenyl  
 4,4'-Bis[N-phenyl-N-(2-pyrenyl)amino]biphenyl
- 25 2,6-Bis[N,N-di(2-naphthyl)amine]fluorene  
 1,5-Bis[N-(1-naphthyl)-N-phenylamino]naphthalene  
 4,4',4''-tris[(3-methylphenyl)phenylamino]triphenylamine

- Another class of useful hole-transporting materials includes
- 30 polycyclic aromatic compounds as described in EP 1 009 041. Tertiary aromatic amines with more than two amine groups may be used including oligomeric materials. In addition, polymeric hole-transporting materials can be used such as

poly(N-vinylcarbazole) (PVK), polythiophenes, polypyrrole, polyaniline, and copolymers such as poly(3,4-ethylenedioxythiophene) / poly(4-styrenesulfonate) also called PEDOT/PSS.

Light-Emitting Layer (LEL)

5                   As more fully described in U.S. Patent Nos. 4,769,292 and 5,935,721, the light-emitting layer (LEL) 109 of the organic EL element includes a luminescent or fluorescent material where electroluminescence is produced as a result of electron-hole pair recombination in this region. The light-emitting layer can be comprised of a single material, but more commonly consists of a host  
10 material doped with a guest compound or compounds where light emission comes primarily from the dopant and can be of any color. The host materials in the light-emitting layer can be an electron-transporting material, as defined below, a hole-transporting material, as defined above, or another material or combination of materials that support hole-electron recombination. The dopant is usually chosen  
15 from highly fluorescent dyes, but phosphorescent compounds, e.g., transition metal complexes as described in WO 98/55561, WO 00/18851, WO 00/57676, and WO 00/70655 are also useful. Dopants are typically coated as 0.01 to 10 % by weight into the host material. Polymeric materials such as polyfluorenes and polyvinylarylenes (e.g., poly(p-phenylenevinylene), PPV) can also be used as the  
20 host material. In this case, small molecule dopants can be molecularly dispersed into the polymeric host, or the dopant could be added by copolymerizing a minor constituent into the host polymer.

                  An important relationship for choosing a dye as a dopant is a comparison of the bandgap potential which is defined as the energy difference  
25 between the highest occupied molecular orbital and the lowest unoccupied molecular orbital of the molecule. For efficient energy transfer from the host to the dopant molecule, a necessary condition is that the band gap of the dopant is smaller than that of the host material. For phosphorescent emitters it is also important that the host triplet energy level of the host be high enough to enable  
30 energy transfer from host to dopant.

                  Host and emitting molecules known to be of use include, but are not limited to, those disclosed in U.S. Patent Nos. 4,768,292; 5,141,671;

5,150,006; 5,151,629; 5,405,709; 5,484,922; 5,593,788; 5,645,948; 5,683,823; 5,755,999; 5,928,802; 5,935,720; 5,935,721; and 6,020,078.

Metal complexes of 8-hydroxyquinoline (oxine) and similar derivatives constitute one class of useful host compounds capable of supporting electroluminescence. Illustrative of useful chelated oxinoid compounds are the following:

- CO-1: Aluminum trisoxine [alias, tris(8-quinolinolato)aluminum(III)]
- CO-2: Magnesium bisoxine [alias, bis(8-quinolinolato)magnesium(II)]
- CO-3: Bis[benzo{f}-8-quinolinolato]zinc (II)
- 10 CO-4: Bis(2-methyl-8-quinolinolato)aluminum(III)- $\mu$ -oxo-bis(2-methyl-8-quinolinolato) aluminum(III)
- CO-5: Indium trisoxine [alias, tris(8-quinolinolato)indium]
- CO-6: Aluminum tris(5-methyloxine) [alias, tris(5-methyl-8-quinolinolato) aluminum(III)]
- 15 CO-7: Lithium oxine [alias, (8-quinolinolato)lithium(I)]
- CO-8: Gallium oxine [alias, tris(8-quinolinolato)gallium(III)]
- CO-9: Zirconium oxine [alias, tetra(8-quinolinolato)zirconium(IV)]

Other classes of useful host materials include, but are not limited to: derivatives of anthracene, such as 9,10-di-(2-naphthyl)anthracene and derivatives thereof as described in US 5,935,721, distyrylarylene derivatives as described in US 5,121,029, and benzazole derivatives, for example, 2, 2', 2''-(1,3,5-phenylene)tris[1-phenyl-1H-benzimidazole]. Carbazole derivatives are particularly useful hosts for phosphorescent emitters.

Useful fluorescent dopants include, but are not limited to, derivatives of anthracene, tetracene, xanthene, perylene, rubrene, coumarin, rhodamine, and quinacridone, dicyanomethylenepyran compounds, thiopyran compounds, polymethine compounds, pyrilium and thiapyrilium compounds, 5 fluorene derivatives, perflanthene derivatives, indenoperylene derivatives, bis(azinyl)amine boron compounds, bis(azinyl)methane compounds, and carbostyryl compounds.

#### Electron-Transporting Layer (ETL)

Preferred thin film-forming materials for use in forming the 10 electron-transporting layer 111 of the organic EL elements of this invention are metal chelated oxinoid compounds, including chelates of oxine itself (also commonly referred to as 8-quinolinol or 8-hydroxyquinoline). Such compounds help to inject and transport electrons, exhibit high levels of performance, and are readily fabricated in the form of thin films. Exemplary oxinoid compounds were 15 listed previously.

Other electron-transporting materials include various butadiene derivatives as disclosed in U.S. Patent No. 4,356,429 and various heterocyclic optical brighteners as described in U.S. Patent No. 4,539,507. Benzazoles and triazines are also useful electron-transporting materials.

#### 20 Cathode

When light emission is viewed solely through the anode, the cathode 113 used in this invention can be comprised of nearly any conductive material. Desirable materials have good film-forming properties to ensure good contact with the underlying organic layer, promote electron injection at low 25 voltage, and have good stability. Useful cathode materials often contain a low work function metal ( $< 4.0$  eV) or metal alloy. One preferred cathode material is comprised of a Mg:Ag alloy wherein the percentage of silver is in the range of 1 to 20 %, as described in U.S. Patent No. 4,885,221. Another suitable class of cathode materials includes bilayers comprising a thin electron-injection layer 30 (EIL) in contact with the organic layer (e.g., ETL) which is capped with a thicker layer of a conductive metal. Here, the EIL preferably includes a low work function metal or metal salt, and if so, the thicker capping layer does not need to

have a low work function. One such cathode is comprised of a thin layer of LiF followed by a thicker layer of Al as described in U.S. Patent No. 5,677,572. Other useful cathode material sets include, but are not limited to, those disclosed in U.S. Patent Nos. 5,059,861; 5,059,862, and 6,140,763.

5                   When light emission is viewed through the cathode, the cathode must be transparent or nearly transparent. For such applications, metals must be thin or one must use transparent conductive oxides, or a combination of these materials. Optically transparent cathodes have been described in more detail in  
10   US 4,885,211, US 5,247,190, JP 3,234,963, US 5,703,436, US 5,608,287, US 5,837,391, US 5,677,572, US 5,776,622, US 5,776,623, US 5,714,838, US 5,969,474, US 5,739,545, US 5,981,306, US 6,137,223, US 6,140,763, US 6,172,459, EP 1 076 368, US 6,278,236, and US 6,284,393. Cathode materials are typically deposited by evaporation, sputtering, or chemical vapor deposition. When needed, patterning can be achieved through many well known methods  
15 including, but not limited to, through-mask deposition, integral shadow masking, for example, as described in US 5,276,380 and EP 0 732 868, laser ablation, and selective chemical vapor deposition.

#### Other Common Organic Layers and Device Architecture

                  In some instances, layers **109** and **111** can optionally be collapsed  
20 into a single layer that serves the function of supporting both light emission and electron transportation. It also known in the art that emitting dopants may be added to the hole-transporting layer, which may serve as a host. Multiple dopants may be added to one or more layers in order to create a white-emitting OLED, for example, by combining blue- and yellow-emitting materials, cyan- and red-  
25 emitting materials, or red-, green-, and blue-emitting materials. White-emitting devices are described, for example, in EP 1 187 235, US 20020025419, EP 1 182 244, US 5,683,823, US 5,503,910, US 5,405,709, and US 5,283,182.

                  Additional layers such as electron or hole-blocking layers as taught in the art may be employed in devices of this invention. Hole-blocking layers are  
30 commonly used to improve efficiency of phosphorescent emitter devices, for example, as in US 20020015859.



This invention may be used in so-called stacked device architecture, for example, as taught in US 5,703,436 and US 6,337,492.

#### Deposition of organic layers

The organic materials mentioned above are suitably deposited  
5 through a vapor-phase method such as sublimation, but can be deposited from a fluid, for example, from a solvent with an optional binder to improve film formation. If the material is a polymer, solvent deposition is useful but other methods can be used, such as sputtering or thermal transfer from a donor sheet. The material to be deposited by sublimation can be vaporized from a sublimator  
10 "boat" often comprised of a tantalum material, e.g., as described in U.S. Patent No. 6,237,529, or can be first coated onto a donor sheet and then sublimed in closer proximity to the substrate. Layers with a mixture of materials can utilize separate sublimator boats or the materials can be pre-mixed and coated from a single boat or donor sheet. Patterned deposition can be achieved using shadow  
15 masks, integral shadow masks (U.S. Patent No. 5,294,870), spatially-defined thermal dye transfer from a donor sheet (U.S. Patent Nos. 5,688,551, 5,851,709 and 6,066,357) and inkjet method (U.S. Patent No. 6,066,357).

#### Encapsulation

Most OLED devices are sensitive to moisture or oxygen, or both,  
20 so they are commonly sealed in an inert atmosphere such as nitrogen or argon, along with a desiccant such as alumina, bauxite, calcium sulfate, clays, silica gel, zeolites, alkaline metal oxides, alkaline earth metal oxides, sulfates, or metal halides and perchlorates. Methods for encapsulation and desiccation include, but are not limited to, those described in U.S. Patent No. 6,226,890. In addition,  
25 barrier layers such as SiO<sub>x</sub>, Teflon, and alternating inorganic/polymeric layers are known in the art for encapsulation.

#### Optical Optimization

OLED devices of this invention can employ various well-known optical effects in order to enhance its properties if desired. This includes  
30 optimizing layer thicknesses to yield maximum light transmission, providing dielectric mirror structures, replacing reflective electrodes with light-absorbing electrodes, providing anti glare or anti-reflection coatings over the display,

providing a polarizing medium over the display, or providing colored, neutral density, or color conversion filters over the display. Filters, polarizers, and anti-glare or anti-reflection coatings may be specifically provided over the cover or as part of the cover.

- 5                   The entire contents of the patents and other publications referred to in this specification are incorporated herein by reference.

                  The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

## PARTS LIST

	10	OLED display device
	11	support
	12	substrate
5	18	first electrode
	19	OLED material
	19R,G,B	red, green and blue emitting OLED material
	30	second electrode
	32	electrode protection layer
10	34	gap
	36	encapsulating cover
	38	tapered fiber optic face plate
	40	fiber optic element
	41	planar surface
15	42	curved surface
	60	optical system
	61	lens
	62	viewer's eye
	101	substrate
20	103	anode
	105	hole injecting layer
	107	hole transporting layer
	109	light emitting layer
	111	electron transporting layer
25	113	cathode
	250	current source
	260	electrical conductors